AN OPEN, SNOW-BASED HYDROLOGIC SYSTEM AS AN ANALOG FOR NOACHIAN MARS. A. P. Zent, NASA Ames Research Center, Moffett Field, CA, 94035, azent@mail.arc.nasa.gov

Properties of Noachian valley network systems on Mars suggests that the conditions under which they formed were marginal for liquid water formation.

The networks are sparsely scattered, are poorly dissected, and tend to be small; a majority occupy areas only a few hundred km in extent. Suspicion that the networks formed by mass wasting are contra-indicated by the discovery of channels within the valleys (Malin et al., 1998). Traditional explanations for the apparent stability of liquid water on ancient Mars have foundered on several familiar problems. First, a very substantial CO_2 atmosphere would be required to bring global average conditions to 273K. The CO_2 should still be present in extensive carbonate deposits that have not been detected. Explanations that call upon groundwater sapping are hampered by the need for a hydrologic system to recharge the groundwater system, which effectively reinstates the need for a heavy greenhouse atmosphere (Goldspiel and Squyres, 1991).

Based upon field experience and some geomorphic similarities between drainage developed in the periglacial terrain in and around the Haughton impact structure, Devon Island, NWT Canada, we have suggested that some of the channel networks may have formed either subglacially, or as ice marginal structures (Lee et al., this issue). A critical lesson from Haughton, which likely applies to Noachian Mars, is that the geomorphology does not reflect processes which operate at the average conditions, but instead reflects processes which operate only transiently at the warmest conditions. Such conditions may arise annually, or only on astronomically determined frequencies, as individual latitudes experience their warmest conditions.

The fundaments of the hypothesis posit that H_2O is supplied to the atmosphere by outgassing during vent or fissure eruptions, or in association with large impacts. Because most of the water would outgas into an extremely cold atmosphere, substantial condensate deposits are an almost inevitable outcome. High heat flow in the vicinity, also a consequence of volcanism and/or impact, leads to subglacial melting. The subsequent ability to flow subareally, and erode channels is contingent upon temperatures periodically exceeding 273 K, and retarding evaporative loss of the flow.

In support of this hypothesis, analysis of erosional valleys and topography in the Thaumasia region of Mars by Tanaka et al. (1999) reveals that valleys tend to originate (1) on Noachian to Early Hesperian large volcanoes, (2) within 50-100 km of stages 1 and 2 rift systems, and (3) within 100 km of Noachian impact craters >50 km in diameter. These geologic preferences explain observations of higher valley-source densities (VSDs) in areas of higher elevations and regional slopes (>1•) because the volcanoes, rifts, and craters form high, steep topography or occur in terrain of high relief. Other high, steep terrains, however, do not show high VSDs. The tendency for valleys to concentrate near geologic features and the overall low drainage densities in Thaumasia compared to terrestrial surfaces rule out widespread precipitation as a major factor in valley formation (as is proposed in warm, wet climate scenarios) except perhaps during the Early Noachian, for which much of the geologic record has been obliterated.

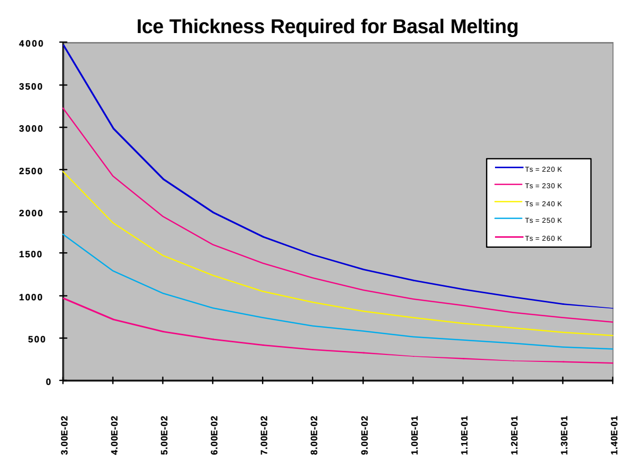
The conditions under which both subglacial melting and retarded evaporation are possible are contingent upon a moderate CO_2 greenhouse. Global average temperatures need not be substantially higher that at present to achieve 273 K in temporally and spatially sparse locations. Globally averaged temperatures on the order of 235 K can be achieved, even at 0.8 Solar luminosity, with a 2 bar CO_2 atmosphere (Haberle, 1998; Kasting, 1991). These calculations are globally averaged, and hence require that much of the surface periodically experience temperatures in excess of 273 K, as a function of obliquity and L_s.

Below we present reality-check calculations to estimate H_2O supply to the surface, the heat flow required to melt the resulting ice, and the subsequent evaporation from liquid H_2O into a dry, CO_2 atmosphere as a function of pressure.

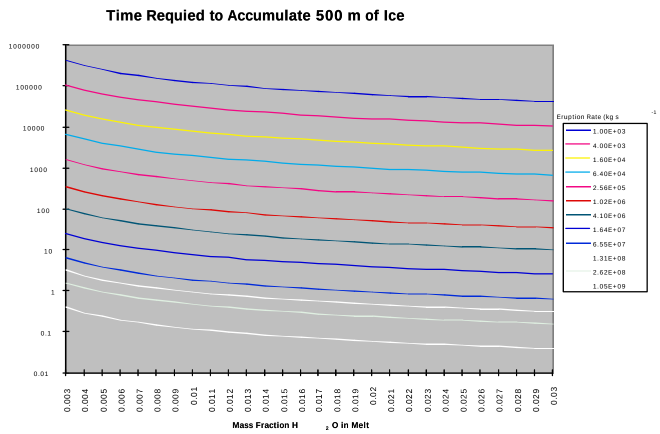
The thickness of ice required for basal melting can be found from

$$Z = K \frac{T_m - T_s}{Q}$$

where T_s is the surface average temperature, K is the thermal conductivity of ice, and Q is the heat flow. Figure 1 shows that if regional average temperatures are 250 K, 500 m of ice will produce basal melting for heat flows on the order of 100 mW m^{-2} s^{-1}, a value not unreasonable for early Mars. How reasonable is it to supply that amount of H_2O to the martian atmosphere?



The hypothesis assumes that H_2O is supplied to the atmosphere through a combination of hydrothermal and volcanic sources. We estimate the ability of a volcanic source to supply the mass of H_2O required to cover the drainage basin in the Margaritifer region (Goldspiel and Squyres, 1991). The area drained by the system is on the order of $8x10^4$ km^2. The time to erupt the required mass is shown in Figure 2 as a function of eruption rate and mass fraction of H_2O in the magma. Reasonable eruption rates for fissure systems are on the order of 10^7 10^8 kg s^{-1}. Reasonable mass fractions of H_2O are on the order of 1%, suggesting eruption durations on the order of years are required (Wilson and Head, 1981).



The evaporation rates from a liquid H_2O surface must be such that melt could travel hundreds of km before evaporating. Evaporation rates for both free convection and wind-driven conditions were calculated by Clow and Haberle (1991).. Evaporation in a free convection regime is minimized, because only diffusion and buoyancy drive the removal of H_2O molecules from the interfacial sublayer. Assuming a 2 bar atmosphere, surface temperatures of 273 K and wind velocities below 0.03 m/s, the critical velocity, the minimum latent heat flux is 0.7 W m^{-2}, which translates to a mass loss of 10^{-6} kg m^{-2} s^{-1}.

Evaporation rates on the order of 10^{-5} to 10^{-6} kg m^2 s^{-1} suggest a stream with 2 m^3s^{-1} discharge, flowing 1 m s^{-1} could persist for hundreds of days and cover distances greater than any valley reach. Unfortunately, the critical wind velocity to maintain free convection is so low that maintaining sufficiently low evaporative fluxes must still be considered an unsolved problem in this hypothesis.

The extreme sparseness of Noachian drainage suggest that conditions were just at or below the threshold for valley formation through early Mars history. Melting associated with volcanically-derived surface ice, and retarded evaporation, both facilitated by CO_2 pressures too low to raise global average temperatures to 273K, are a possible explanation for the valley formation. This hypothesis is suggested by drainage at the Haughton crater, where annual average temperatures are on the order of 255 K, yet abundant fluvial erosion takes place, almost entirely during the warmest few weeks of the year. Similar erosion might have occurred on Mars at the warmest, highest pressure conditions, only sporadically achieved.

References:

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